PATENT COOPERATION TREATY

PCT

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference DM/CP/P12923PC	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/GB 03/02314	International filing date *(day/month/year)* 29.05.2003	Priority date *(day/month/year)* 30.05.2002
International Patent Classification (IPC) or both national classification and IPC G02B6/35		
Applicant THE UNIVERSITY COURT OF THE UNIVERSITY OF...et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 14 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
24.12.2003	08.09.2004
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Mircescu, A Telephone No. +49 89 2399-7645

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB 03/02314

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1-35 as originally filed

Claims, Numbers

1-63 received on 03.06.2004 with letter of 03.06.2004

Drawings, Sheets

1/19-19/19 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☐ the claims, Nos.:

   ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-63
	No:	Claims	
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-63
Industrial applicability (IA)	Yes:	Claims	1-63
	No:	Claims	

2. Citations and explanations

see separate sheet

Reference is made to the following documents:

D1: US-B1-6180940
D2: US-A-4872755
D3: US-A-5838844

A. Citations and explanations in respect of Item V:

1. The two aspects of the present application defined in points 1.1 and 1.2, respectively, are equivalent to claims 1-63 of the present application. The introduction of this equivalence was necessary in order to achieve procedural efficiency due to the excessive number of independent claims of the present application.

1.1 It is clear in the light of the description (see page 4, lines 7-26; page 5, lines 1-22; page 9, lines 25-26; page 10, line 1) that the following features characterize a first aspect of the invention: a device for selecting a photon or a beam of photons in the optical wavelength range, comprising:

(i) means for selecting photons based on their spin and/or orbital angular momentum;

(ii) means for directing photons from the input to a selected output dependent on their spin and/or orbital angular momentum;

(iii) the means for directing photons comprises at least one interferometer;

(iv) the interferometer comprises two arms with one prism in each arm, the prisms being rotated with respect to one another;

(v) a hologram for the amplification of the orbital angular momentum of each photon;

(vi) a polarisation beam splitter.

1.2 It is clear in the light of the description (see page 4, lines 7-26; page 5, lines 1-22; page 14, lines 7-22; page 30, lines 21-26; page 31, lines 1-20; page 33, lines 2-5) that the following features characterize a second aspect of the invention: a device

for selecting a photon or a beam of photons in the microwave wavelength range, comprising:

(j) means for selecting photons based on their spin and/or orbital angular momentum;

(jj) means for directing photons from the input to a selected output dependent on their spin and/or orbital angular momentum;

(jjj) the means for directing photons comprises a phased-array antenna with double orthogonal dipoles.

1.3 The subject matter of claims 1-63 which define both aspects of the invention discussed in 1.1 and 1.2 is not completely disclosed in documents D1, D2, or D3, and therefore the subject matter of claims 1-63 is novel (Art 33(2) PCT).

2.1 Document D1 which is considered to represent the closest prior art, discloses according to essential features of the first aspect of the invention a device for selecting a photon or a beam of photons (see D1, column 1, lines 33-61), comprising:

(i) means for selecting photons based on their spin and/or orbital angular momentum (see D1, column 1, lines 57-61);

(ii) means for directing photons from the input to a selected output dependent on their spin and/or orbital angular momentum (see D1, column 1, lines 57-61);

(v) a hologram for the amplification of the orbital angular momentum of each photon (see D1, column 2, lines 41-53; column 3, lines 11-20).

The subject matter of the first aspect of the invention differs from that described in D1 in that the measurement of the orbital momentum of the photons is realized with a two-arm interferometer.

2.2 The objective problem to be solved by the present invention may therefore be regarded as how to effectively measure the orbital angular momentum of photons in the optical frequency range.

2.3 In consulting the prior art in the general field of measurement of optical phase differences, the skilled person, wishing to find a solution to overcome the above mentioned problem, would come across the document D2 which describes an apparatus for measuring the phases of photons (see D2, column 2, lines 38-64), comprising:

(iii) the means for directing photons comprises at least one interferometer (see D2, figures 4 and 5);

(iv) the interferometer comprises two arms with one prism in each arm, the prisms being rotated with respect to one another (see D2, column 9, lines 15-31);

(vi) a polarisation beam splitter (see D2, column 6, lines 8-36).

The skilled person would therefore arrive, without the exercise of inventive skill, at the apparatus for measuring and directing photons based on their spin and/or orbital angular momentum in the optical frequency range of the first aspect of the invention.

The subject matter of the first aspect of the invention therefore does not involve an inventive step, Art 33(3) PCT.

3.1 Document D1 which is considered to represent the closest prior art, discloses according to essential features of the second aspect of the invention a device for selecting a photon or a beam of photons (see D1, column 1, lines 33-61), comprising:

(j) means for selecting photons based on their spin and/or orbital angular momentum (see D1, column 1, lines 57-61);

(jj) means for directing photons from the input to a selected output dependent on their spin and/or orbital angular momentum (see D1, column 1, lines 57-61).

The subject matter of the second aspect of the invention differs from that described in D1 in that the measurement of the orbital momentum of the photons is realized with a phased-array antenna.

3.2 The objective problem to be solved by the present invention may therefore be regarded as how to effectively measure the orbital angular momentum of photons in the microwave frequency range.

3.3 In consulting the prior art in the general field of measurement of microwave phase differences, the skilled person, wishing to find a solution to overcome the above mentioned problem, would come across the document D3 which describes an apparatus for measuring the phases of photons (see D3, column 2, lines 38-64), comprising:

(jjj) means for directing photons comprises a phased-array antenna with double orthogonal dipoles (see D3, column 3, lines 5-61).

The skilled person would therefore arrive, without the exercise of inventive skill, at the apparatus for measuring and directing photons based on their spin and/or orbital angular momentum in the microwave frequency range of the second aspect of the invention.

The subject matter of the second aspect of the invention therefore does not involve an inventive step, Art 33(3) PCT.

4. Since the subject matter of both aspects of the invention does not involve an inventive step according to the discussion in points 1-3, the subject matter of claims 1-63 which define both aspects of the invention also a fortiori does not involve an inventive step (Art 33(3) PCT).

5. The subject matter of claims 1-63 is industrially applicable and therefore complies with Art 33(1) PCT.

B. Further remarks made in respect of the present application

1. It is stated that an independent claim comprising features (i)-(vi), (j)-(jjj) mentioned in points A1.1 and A.1.2 and additionally the features of

(1) coding and decoding photons in a switch,
(2) selecting and directing photons based on angular and/or orbital angular momentum and
(3) information transfer through the switch

would have been novel (Art 33(2) PCT) and would also have involved an inventive step (Art 33(3) PCT) when compared to the prior art documents D1, D2, and D3. Industrial applicability (Art 33(1) PCT) of the mentioned claim would also have been given.

The examiner could not, however, find the implementation of the solution mentioned in points (1)-(3) in claims 1-63; and therefore the objection regarding the inventive step (Art 33(3) PCT) given in points A1-A5 remains valid.

2. It is stated that the application discloses means and methods for building a switch operable exclusively in the optical and microwave wavelength range. These two wavelength ranges are substantially different from the technical point of view. In the microwave wavelength range antennas are used to select and direct photons; in the optical wavelength range a prism-based interferometer is taken as selector/director.

Means and methods for other wavelength ranges (like the X-ray or Gamma wavelength range) are not disclosed in the application; and, as a consequence, the claiming of other wavelength ranges contravenes Art 5 PCT since the description does not clearly and completely describe how these wavelength ranges are operated on. In order to comply to Art 5 PCT the claimed subject matter should have been limited to the microwave and optical wavelength range.

Since the examiner regards the microwave and optical wavelength range as essential features of the application and not as mere examples only, in order to also comply to Art 6 PCT these essential features should have been mentioned in the independent claim.

3. It is stated that according to the Standard Model of particle physics the material in the universe is made up of elementary fermions interacting through fields to which they are the sources. The particles associated with the interaction fields are elementary bosons.

The quanta of the electromagnetic fields are the leptons and quarks as the fermions and the photons as the bosons. Therefore the electromagnetic energy, as mentioned in the claims of the present application, is made up of the fermionic and bosonic part, and not determined by the bosonic fraction only.

As a consequence, the claiming of also fermionic particles contravenes Art 5 PCT since the description does not clearly and completely describe how these particle types are operated on. In order to comply to Art 5 PCT the claimed subject matter should have been limited to the bosonic particle type which is defined regarding the electromagnetic field by the photon.

Since the examiner regards the photon as an essential feature of the application and not as a mere example only, in order to comply to Art 6 PCT this essential feature should have been mentioned in the independent claim.

4. Although claims 1, 14, 30, 35, 44, 45, 47, 50, 59, 60, 61, 62, and 63 have been drafted as separate independent claims, they appear to relate effectively to the same subject matter and to differ from each other only with regard to the definition of the subject matter for which protection is sought and in respect of the terminology used for the features of that subject-matter. The aforementioned claims therefore lack conciseness. Moreover, lack of clarity of the claims as a whole arises, since the plurality of independent claims makes it difficult, if not impossible, to determine the matter for which protection is sought, and places an undue burden on others seeking to establish the extent of the protection.

   Hence, claims 1, 14, 30, 35, 44, 45, 47, 50, 59, 60, 61, 62, and 63 do not meet the requirements of Art 6 PCT.

5. Claim 49 does not meet the requirements of Art 6 PCT in that the matter for which protection is sought is not clearly defined. The following functional statements do not enable the skilled person to determine which technical features are necessary to perform the stated functions:

   claim 49: prism is formed of optical quality glass: it is clear in the light of the description (page 13, line 2) that it is formed of BK7.

CLAIMS

1. A device comprising:

at least one input;

at least one output; and

means for selecting the or at least one of the at least one outputs, wherein the selection is dependent upon at least an orbital angular momentum or orbital and spin angular momentum of at least one electro-magnetic energy input or appearing at the at least one input, in use.

2. A device as claimed in claim 1, wherein there are provided a plurality of outputs.

3. A device as claimed in any preceding claim, wherein the at least one electro-magnetic energy comprises at least one electro-magnetic signal or beam.

4. A device as claimed in any preceding claim, wherein the electro-magnetic energy comprises a photonic energy comprising at least one photon.

5. A device as claimed in any preceding claim, wherein the means for selecting comprises means for directing or switching the at least one electro-magnetic energy to the selected at least one of the at least one outputs.

6. A device as claimed in any preceding claim, wherein the selected at least one of the at least one outputs comprises one of the at least one outputs.

7. A device as claimed in any preceding claim, wherein an output electro-magnetic energy, in use, appears at the selected at least one of the at least one outputs.

8. A device as claimed in claim 7, wherein the output electro-magnetic energy comprises at least part of the at least one input electro-magnetic energy.

9. A device as claimed in any of claims 1 to 8, wherein the device is adapted for use at optical wavelengths.

10. A device as claimed in any of claims 1 to 8, wherein the device is adapted for use at or within a frequency range selected from one of: radio, millimetre wave or microwave.

11. A device as claimed in any preceding claim, wherein the device is adapted for use as a switching or multiplexing device.

12. A device as claimed in any of claims 1 to 11, wherein the at least one electro-magnetic energy comprises and electro-magnetic signal comprising at least one photon.

13. A device as claimed in any of claims 1 to 12, wherein the at least one electro-magnetic energy comprises an electro-magnetic signal comprising a beam.

14. An electro-magnetic device, such as an optical device, comprising:

at least one input;

a plurality of outputs;

means for directing at least one electro-magnetic signal or photon from one of the at least one inputs to a selected of the outputs, the selection being dependent upon at least an orbital angular momentum of the or each at least one electro-magnetic signal or photon.

15. A device as claimed in claim 1 or claim 14, wherein the selection is dependent upon:

orbital angular momentum, l (OAM) solely; or

orbital angular momentum and spin angular momentum, s (sAm) combined, that is, total angular momentum, j.

16. An electro-magnetic device as claimed in claim 14, wherein the means for directing comprises at least one interferometer.

17. An electro-magnetic device as claimed in claim 16, wherein the or each interferometer includes means for inducing, in use, a rotation or invertion of an electro-magnetic mode of an electro-magnetic signal or photon such as a light mode of a photon in at least one arm of the interferometer.

18. An electro-magnetic device as claimed in claim 17, wherein the means for inducing a rotation comprises at least a first prism and a second prism.

19. An electro-magnetic device as claimed in claim 18, wherein at least one prism is positioned in each arm of the interferometer.

20. An electro-magnetic device as claimed in claim 18, wherein the first prism and second prism are positioned in one arm of the interferometer.

21. An electro-magnetic device as claimed in claim 19, wherein the first prism positioned in a first arm of the interferometer is rotated with respect to the second

prism positioned in a second arm of the interferometer, the second prism being turned through an angle, α around a second optical path with respect to the orientation of the first prism in a first optical path.

22. An electro-magnetic device as claimed in any of claims 18 to 21, wherein the first prism and second prism introduce a phase shift in each passing photon.

23. An electro-magnetic device as claimed in any of claims 18 to 22, wherein each prism is a Dove prism.

24. An electro-magnetic device as claimed in any of claims 14 to 23, wherein the electro-magnetic device is an optical device comprising a one piece device in the form of a monolithic block.

25. An electro-magnetic device as claimed in any of claims 14 to 24, wherein the device includes means for rotation of a polarisation state and hence spin angular momentum of a photon or photons.

26. An electro-magnetic device as claimed in claim 25, wherein the means for rotation allows an output of the device to be determined by total angular momentum of a photon or photons not solely by orbital angular momentum.

27. An electro-magnetic device as claimed in either of claim 25 or 26, wherein the means for rotation comprise at least one half-wave retarder.

28. An electro-magnetic device as claimed in claim 16, or claims 17 to 27 when dependent upon claim 16, wherein the means for rotation are disposed within the or each interferometer.

29. An electro-magnetic device as claimed in claim 16, or claims 17 to 27 when dependent upon claim 16, wherein the means for rotation are disposed outwith the or each interferometer.

30. An optical device comprising:

an input;

a first beam splitting means;

a second beam splitting means;

a first reflective means;

a second reflective means;

a first prism;

a second prism; and

at least a first output and a second output,

wherein the first beam splitting means, the second beam splitting means, the first reflective means, and the second reflective means are arranged to form an

interferometer arrangement, with the first prism disposed in a first arm of the interferometer arrangement and the second prism disposed in a second arm of the interferometer arrangement, the input leading to the first beam splitting means and the at least first output and second output leading from the second beam splitting means, and wherein, in use, at least one photon is input into the device which determines or selects, based on an orbital angular momentum of the photon, the output to which the photon will pass.

31. An optical device as claimed in claim 30, wherein the first prism is rotated with respect to the second prism.

32. An optical device as claimed in either of claims 30 or 31, wherein the first prism and second prism introduce a phase shift in the or each passing photon.

33. An optical device as claimed in any of claims 30 to 32, wherein each prism is a Dove prism.

34. An optical device as claimed in any of claims 30 to 33, wherein the optical device comprises a one piece device in the form of a monolithic block.

35. An apparatus, such as an optical apparatus, comprising a plurality of cascaded devices according to claims 1 to 13, electro-magnetic devices according to claims 14 to 29, or optical devices according to claims 30 to 34, wherein the devices are arranged with an at least one output of one device communicating with another device.

36. An apparatus as claimed in claim 35, wherein the apparatus comprises a signal processing apparatus, such as optical signal processing apparatus.

37. An apparatus as claimed in either of claims 35 or 36, wherein a hologram is disposed between an output of the one optical device and an input of the another optical device.

38. An apparatus as claimed in clam 37, wherein, in use, the hologram acts to increase the orbital angular momentum of the or each photon which passes through the hologram.

39. A system, such as an optical system, including at least one device or apparatus, such as a optical device or optical apparatus, according to any of claims 1 to 38.

40. A system as claimed in claim 39, wherein where the device or apparatus is an optical device or apparatus, the device or apparatus providing the system with at least two possible output groups of output photons or states, the groups or states being selected by the device or apparatus depending on an orbital angular momentum feature of an input photon.

41. A system as claimed in either of claims 39 or 40, wherein the system further comprises a detector arrangement to detect a state of at least one output of the device or apparatus.

42. A system as claimed in any of claims 39 to 41, wherein the system is an optical communications system, such as a free space optical communication system.

43. A device as claimed in any of claims 1 to 13, an electro-magnetic device as claimed in any of claims 14 to 29, an optical device as claimed in any of claims 30 to 34, an apparatus as claimed in any of claims 35 to 38, or a system as claimed in any of claims 39 to 42, wherein the device/apparatus/system is adapted for use at a wavelength(s) selected from far infra-red to far ultra violet, such as near infra-red or visible, such as

particularly 700nm to 3μm, and most particularly 1.3μm to 1.6μm.

44. A method of determining a feature of orbital angular momentum of an electro-magnetic energy such as a or each photon in an optical signal, the method comprising the steps of:

providing a device, such as an optical device comprising:

at least one input;

a plurality of outputs;

means for directing an electro-magnetic energy, such as at least one photon from one of the at least one inputs to a selected of the outputs, the selection being dependent upon an orbital angular momentum of the electro-magnetic energy such as the/each at least one photon;

inputting the electro-magnetic energy into the device;

detecting a feature of the orbital angular momentum of the electro-magnetic energy;

directing the electro-magnetic energy to a selected one of the plurality of outputs, the selected output for the electro-magnetic energy being selected by the detected feature of the electro-magnetic energy.

45. A method of communication or signal processing, such as optical communication or signal processing, the method comprising the steps of:

providing a detection system, such as an optical detection system, comprising at least one device, such as an optical device, and a detection means;

receiving at least one electro-magnetic energy or signal, such as at least one photon;

passing the at least one electro-magnetic energy through the detection system comprising at least one device so as to determine an orbital angular momentum of said at least one electro-magnetic energy;

directing the at least electro-magnetic energy from the device to the detection means so as to identify said feature of orbital angular momentum of said electro-magnetic energy.

46. A method according to claim 46, wherein the method further comprises the steps of:

providing at least one transmission system, such as an optical transmission system; and

transmitting at least one electro-magnetic energy, such as at least one photon, to be received by said detection system.

47. A prism, the prism comprising:

an input;

an output; and

means for inverting a transverse cross-section of an optical beam or light mode transmitted through the prism without changing the polarisation state.

48. A prism as claimed in claim 47, wherein the input and the output are normal to an optical beam transmission axis.

49. A prism as claimed in either of claims 47 or 48, wherein the prism is formed of optical quality glass.

50. A prism comprising:

a first end face; and

a second end face, arranged substantially parallel to said first end face; and

a side face disposed between said first end face and said second end face, the side face being formed of two planar areas disposed in a inwardly orientated 'V' shape.

51. A prism as claimed in claim 50, wherein the prism acts, in use, to invert a transverse cross-section of an optical beam transmitted through the prism.

52. A prism as claimed in either of claims 50 or 51, wherein the prism is polarisation insensitive when an optical beam is input to the prism via an end face.

53. An optical device comprising two prisms according to claims 50 to 52.

54. An optical device as claimed in claim 53, wherein the optical device further comprises two beam splitters.

55. An optical device as claimed in either of claims 53 or 54, wherein the optical device is a block unit, with planar faces of each component allowing each component to be arranged directly adjacent each other component.

56. An optical device as claimed in claim 55, wherein the block unit is a monolithic block.

57. An optical apparatus comprising a plurality of optical devices according to any of claims 53 to 55.

58. An optical communication system or signal processing system comprising at least one optical device according to any of claims 53 to 56 or optical apparatus according to claim 57.

59. A phased-array antenna adapted to generate or form an electro-magnetic energy, signal or beam with orbital angular momentum.

60. Use of a phased-array antenna to generate or form an electro-magnetic energy, signal or beam with orbital angular momentum.

61. A phased-array antenna adapted to detect orbital angular momentum in or of an electro-magnetic energy, signal or beam.

62. Use of a phased-array antenna to detect orbital angular momentum in or of an electro-magnetic energy, signal or beam.

63. A method of communication or signal processing using electro-magnetic energies, signals or beams, the method comprising: multiplexing using orbital angular momentum of electro-magnetic beams by generation and sensing using phase differences in arrays of antenna.

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